An Analysis of Steam Process Heater Condensate Drainage Options

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ABSTRACT

The production and reliability of performance of steam process heaters can be significantly affected by the condensate drainage design that is employed. The current variety of drainage options can be confusing to a system designer who is unaware of the reasons for each specific design. An understanding of the various types and why they may be used follows.

BACKGROUND

For simplicity, the terminology "process heater" is intended to mean any steam heat exchanger, coil, or kettle which uses steam as the primary fluid to transfer heat to a product. While generally intended for production purposes, this terminology can also be used to refer to HVAC applications. The reason that all of these heater types can be grouped together is because even though they incorporate different exchanger designs on the product side, they all are intended to transfer steam heat in an efficient and cost effective heating manner. In that sense, they all use the steam to provide a certain level of heat transfer and drain the by-product, condensate, away from the heater so that new steam can be introduced and controlled to heat additional product.

What is intriguing about this simple goal is that there are currently a variety of installation designs to accomplish the removal of that condensate, and these provide various levels of production performance depending on the environmental conditions of the specific heater application. What can be confounding is that some of these drainage options may work very well in one scenario, and yet fail miserably in another depending on the conditions. When successful in a previously troublesome application, a particular installation design may create a sense of comfort within an engineering department and later become a standard practice for a facility. Later it can have decidedly mixed results when used for an application for which it cannot perform well enough to meet design expectations. This situation may have tremendous energy and production implications and can usually be easily identified in advance.

IDENTIFYING THE SYMPTOMS

Telltale signs for those installations with unsuitable condensate drainage include:

- Condensate being visibly wasted from the heat exchanger discharge side, either from a hose connection at the strainer, or an opened union or drain valve on the steam trap's outlet piping. In this case, the condensate is no longer available to be returned through the return line, and its valuable energy is needlessly sacrificed to grade so that required production performance levels can be achieved.
- The presence of severe hammering in the exchanger itself or in the return piping downstream of the heater. There are a variety of causes for this type of hammering, but in the worst case its cause can be attributed to significant amounts of preventable steam loss.
- Product variance much greater than expectations.
- Dramatic temperature stratification of the heater's exterior surface where steam is shell-side.
- A higher than average maintenance requirement for head gasket or tube bundle failure.

COURSE OF ACTION

The optimum solution is to specify a condensate drainage design that removes all condensate from the heater rapidly. This is where confusion over the best design has traditionally occurred. While the target of high performance heat exchanger installation design prevails, a full understanding of the options and when their use is indicated is often not clear.

Therefore, the purpose of this presentation is to examine the common types of heat exchanger drainage designs, and describe the instances where each can perform suitably. Those installation designs are slightly different when steam is tube-side versus shell-side, and the piping options for both instances follow:

Potential Installation Designs

- Steam Inlet Control Valve with Outlet Steam Trap (Figure A).
- Steam Inlet Control Valve with Outlet Level Pot (Figure B).
- Steam Inlet Control Valve with Outlet Condensate Level Control (Figure C).
- Condensate Outlet Control Valve and Level Override (Figure D).
- Condensate Outlet Control Valve for Drainage and Set Point Control (Figure E).
- Steam Inlet Control Valve with Outlet Condensate Pump/Trap Drainage (Figure F).

An in-depth knowledge of the various options will help in providing the most effective condensate drainage installation for each given circumstance. With a clear understanding of these options and when to use them, the designer will be able to maximize the energy usage and production performance of each application according to the budgetary constraints of the allocated capital.

Steam Inlet Control Valve With Outlet Steam Trap (Figure A)

This is the traditional approach to supplying steam and drainage condensate from process heaters. It offers a relatively simple installation, with easy troubleshooting and low cost maintenance. It accomplishes the control value by modulating steam temperature and rapid drainage of condensate from the tube bundle. It is the primary method of choice where the pressure supplying the steam trap (P1) is always greater than the back pressure (P2) because it always keeps steam on the tube bundle under these conditions. The figure shows condensate draining by gravity, but this is not an actual requirement. Condensate can elevate with this design, and it can operate against back pressure, provided that the differential from P1:P2 is always positive.

Is the differential pressure really positive?

The actual pressure differential P1:P2 may not really be positive when it appears to be so. For a true understanding, it is necessary to study the pressure dynamics of the control valve as it modulates to achieve the heat balance with the set point. As the heating demand lowers, the control valve will modulate and lower the pressure in the steam space. When this occurs, P1 will often become lower than P2 even though the supply pressure to the control valve is substantially greater than P2. This condition where P1 modulates a lower pressure than P2 is known as a "stall". The effect is that Figure A's installation design can work very well in all cases until it is used in applications where stall occurs. Then the system will provide less desirable results.

What happens during "stall"?

The system partially floods the tube bundle. This creates a variety of undesirable effects, including inconsistent product quality and large variations from the set point. Other typical symptoms include corrosion, thermal shock, and hammering of the heater with damage to either the heater itself or the outlet steam trap.

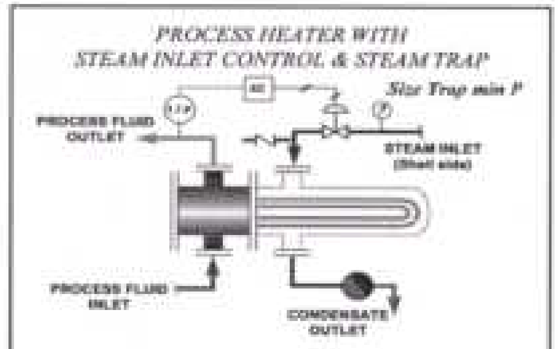

FIGURE A

Steam Inlet Control Valve With Outlet Level Pot (Figure B)

This system is basically a modification of the installation shown in Figure A. It has been used as a steam trap substitute in applications of very high pressure and high capacity where these requirements are beyond the capabilities of a traditional steam trap. It has also been used for instances where "stall" occurs and the resulting hydraulic shock has severely damaged the outlet steam trap.

The only difference between the systems shown in Figure A and Figure B is in the design of the trap. Figure A uses a traditional, self-contained steam trap, and Figure B substitutes an electronic steam trap in the form of a level pot receiver, level sensing from the transmitter, and automatic valve opening and closing through the controller and control valve. Although a more complex system, the condensate drainage function is virtually identical to a simple, mechanical steam trap. Generally, the cost of this electronic steam trap option is greater than a self-contained trap.

Because of the durability of the components, this system can improve the symptom where a self-contained steam trap has been regularly damaged from severe water hammer, but it does not correct the cause. In this sense, it is only a band-aid, and additional symptoms of corrosion and production variance from the control value will not be corrected by this option.

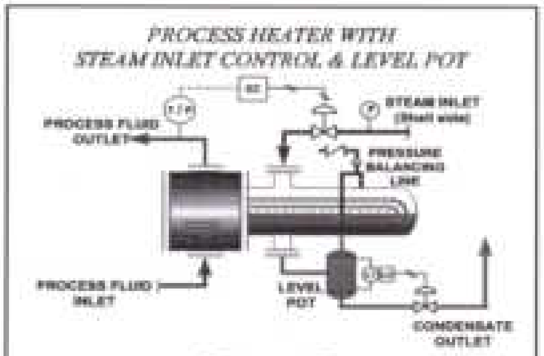

FIGURE B

Steam Inlet Control Valve With Outlet Condensate Level Control (Figure C)

This solution has been used in some cases to combat stall conditions. In this case, a sufficiently high steam pressure is used on the control valve inlet to ensure a positive pressure differential P1:P2. Because of the possibility of large pressure and temperature changes, some heater surface area is removed by intentional flooding. Limiting the effective surface area in this manner can lower the range of the control swing.

This insulation will provide positive pressure differential for P1:P2, but causes increased fouling on the tube bundle which is usually exposed to high pressure steam. Troubleshooting this installation will be complex, and corrosion, head gasket failure, and thermal shock can be expected maintenance issues because the tube bundle is stratified with condensate and steam.

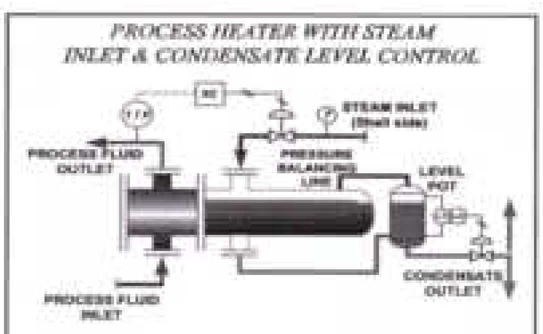

FIGURE C

Condensate Outlet Control Valve and Level Override (Figure D)

A common alternative used by some design engineers is to completely eliminate inlet steam control and select outlet condensate control instead. In this design, the outlet control serves as both control valve and steam trap. The installation does not stall because the steam pressure does not modulate. The result is that the pressure on the tube bundle is always greater than the back pressure. The level pot is used to reduce the possibility of live steam loss, and the tube bundle is intentionally flooded to remove excess surface area. Then the available tube bundle area becomes the control variable.

Under stall conditions, this system can be a lower cost alternative than the steam inlet control and outlet level pot design of Figure B. The outlet control and level pot are actually sized similarly to Figure B, but this system completely eliminates the cost of the inlet control valve. Additionally, the heater is exposed to higher pressure steam at all times, so its required surface area may be reduced due to the expected higher temperature of the unmodulated steam.

This system can provide acceptable process control in instances of limited demand variation. However, the more the demand changes, there may be instances of significant deviation from the control value. This is due to at least two factors. Changing water level on a tube bundle is a much slower process than adjusting steam pressure. Therefore, the process to adapt to demand changes in an outlet control design by moving a water level is significantly slower than when moving steam that occurs in steam inlet control installations. The result is a greater lag in response to demand changes. Also, once the water level is moved, the newly exposed or covered heat transfer area encounters a drastically changed “U” value. This is because of the substantially different heat transfer rates between hot condensate and steam. The effects of this difference will be in proportion to the amount of new surface area exposure. The more the demand change and subsequent tube exposure, the more dramatic the change in “U” and the resultant variation from the control value. In short, wider temperature or pressure swings are typical of this control method.

An additional issue with this design is that the heater’s life begins with intentional flooding, then exposes increasingly more area as the tube surface becomes fouled. Eventually, the entire surface can become exposed and still not satisfy the process demand due to fouling. Then, such systems programmed with a level override priority can actually blow live steam through the control valve, thereby pressurizing the return line. This leads to a high energy cost and detracts from the production rate of all other heaters draining into the increased back pressure of the same return heater.

Additionally, without any special provisions, the heater will remain flooded at shutdown and tube corrosion will be exceptionally high in these cases.

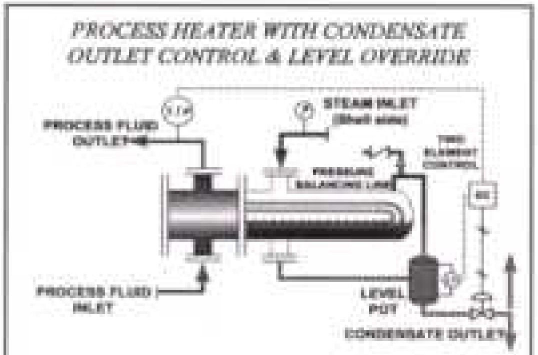

FIGURE D

Condensate Outlet Control Valve for Drainage and Set Point Control (Figure E)

This installation is virtually identical to Figure D, except that the cost and leak protection of the level pot is eliminated. The installed cost is lower by this elimination, but the energy consumption can be significantly higher due to live steam loss throughout the heater life. All other characteristics of Figure D remain.

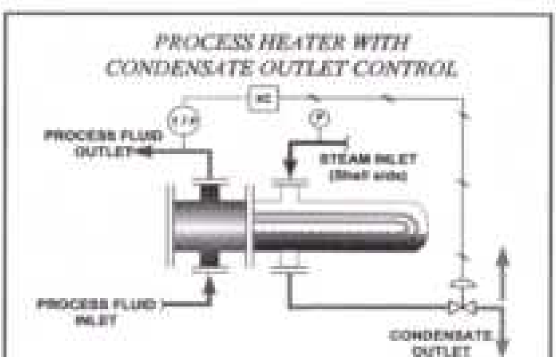

FIGURE E

Steam Inlet Control Valve With Outlet Condensate Pump/Trap Drainage (Figure F)

The installation in Figure A is a perfect design in which stall and hydraulic shock conditions do not occur. However, for those severe conditions, Figure A cannot be used, and the other designs of Figures B through E were most likely developed to deal with them. Unfortunately and for the reasons explained above, those other designs are not always optimal when dealing with stall. Figure F provides a suitable maximum benefit design for stall conditions.

The system utilizes a piece of equipment known as pump/trap combination. This can be either a single combined pump/trap unit, or employ two separate products in an engineered package. Usually suitable for pressures up to 150 psig steam, pump/traps allow the system to adapt quickly to demand changes and drain condensate under all pressure conditions.

The design requires that inlet steam control is used. This is to provide for the most rapid adjustment to demand changes possible. In an inlet steam valve installation, the control valve adjusts the steam pressure and temperature rapidly, as soon as the sensor detects a variance against the control value. Condensate is always drained from the system by the pump/trap, so the exposed surface area is constant allowing the modulated steam pressure to equalize to the required load. The pump/trap has a multi-functional capability.

<u>As a Trap</u>. When the pressure differential of P1:P2 is positive, the steam space pressure drives condensate through the unit, and steam is contained by the included trap. Operation under these conditions is similar to Figure A.

<u>As a Pump</u>. When the pressure differential of P1:P2 is negative, then the condensate fills the pump cavity and is pumped downstream before the process heater can be flooded. The result is that the heater tubes are always exposed only to steam and not to flooded condensate. The main point is that only the small pump body receives high pressure steam, not the entire process heater as occurs in Figures C, D, and E.

Where suitable to be employed, Figure F systems of steam inlet control and pump/trap drainage minimize energy waste, high control variance, corrosion, thermal shock, and stratification during production. When properly designed, they also drain the equipment during shutdown to avoid the high corrosion that occurs from stagnant condensate. They can minimize fouling as the steam temperature used is always the lowest possible to achieve equilibrium with the demand. The motive steam used to pump the condensate in the system is returned to the process heater to utilize its heat in the process. This guarantees an extremely low cost pumping solution while maximizing the production rates of steam process heaters.

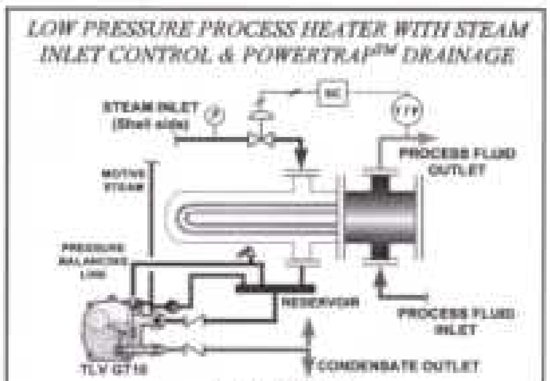

FIGURE F

Conclusions

The author's preference is for the drainage methods of Figure A and Figure F as primary solutions, and then Figure B when neither of the first two alternatives will meet the application requirements. In cases where neither Figures A, F, or B will meet the application demands, then Figure D may be considered provided that the user accepts the limitations of this design.

Acknowledgments

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References

1. Mathur, Jimmy, 1973. "Performance of Steam Heat-Exchangers", *Chemical Engineering*, September 3, pp. 101-106.
2. McCarthy, Alfred J. & Smith, Brian, R., 1995. "Reboiler System Design: The Tricks of the Trade", *Chemical Engineering Progress*, May, pp. 33-47.
3. Mehra, Davinder K., 1985. "Troubleshooting Problems With Heat Exchangers", *Chemical Processing*, August, pp.36-38.
4. Pathak, Vijay K. & Rattan, Inder S., 1988. "Turndown Limit Sets Heater Control", *Chemical Engineering*, July 18, pp. 103-105.
5. Risko, James R., 1997. "Maximize Productivity From Steam Process Heaters Through Proper Condensate Drainage", *TLV Design Guide*.
6. Risko, James R., 1996. "Managing Steam Condensate is Key to Heater Efficiency", *Chemical Engineering*, July pp. 114-119.
7. Risko, James R., 1996. "Draining Condensate From Steam Process Heaters", *Plant Engineering*, March, pp. 74-76.
8. Risko, James R., 1994. "Complete Condensate Drainage From Equipment", *TLV Design Guide*.
9. Risko, James R., 1988. "Handling Steam Condensate", *Plant Engineering*, March 10, pp. 146-149.
10. Schwartz, Marvin P., 1982. "Four Types Of Heat Exchanger Failures", *Plant Engineering*, December 23, pp. 45-50.